Conference Paper, Published Version

Miura, Yusuke; Minami, Masato; Udo, Keiko; Mano, Akira

Sediment Transport around Headlands in the Southern Sendai Coast

Sediment Transport around Headlands in the Southern Sendai Coast

Yusuke MIURA[1], Masato MINAMI[2] , Keiko UDO[3] and Akira MANO[4]

[1]Member of JSCE, Graduate Student, Dept. of Civil Eng., University of Tohoku
(6-6-11-1110, Aoba, Sendai, 980-8579, JAPAN)
E-mail:miura@potential1.civil.tohoku.ac.jp
[2]Member of JSCE, Associate Professor, Hachinohe National Collage of Technology
(16-1, Uwanotai, Tamonoki, Hachinohe, Aomori, 039-1192, JAPAN)
E-mail:minami-z@hachinohe-ct.ac.jp
[3]Member of JSCE, Associate Professor, Dept. of Civil Eng., University of Tohoku
(6-6-11-1110,Aoba, Sendai, 980-8579, JAPAN)
E-mail:udo@potential1.civil.tohoku.ac.jp
[4]Member of JSCE, Professor, Dept. of Civil Eng., University of Tohoku
(6-6-11-1110,Aoba, Sendai, 980-8579, JAPAN)
E-mail:mano@civil.tohoku.ac.jp

The Southern Sendai Coast is approximately 65-km long curved coast facing the Pacific Ocean in the northern part of Japan, where is a typical coastal erosion area in this country. Predominant wave direction is from east to southeast, and the direction of longshore sediment transport is south to north. The sediment was supplied to the coast due to erosion of coastal cliff located 50 km southern southeast of the coast in 1960s. In 1970s, however, the coast began to erode due to prevention of the coastal cliff erosion and development of extensive port between the coast and the cliff. To prevent the erosion and to control the longshore sediment transport, eight headlands have been constructed at intervals of 1 km since 1997 to present. The purpose of this study is to understand macroscale beach topographic features in the vicinity of the headland from field data, and to simulate this features using FUNWAVE based on the fully nonlinear Boussinesq model of Wei et al.[1)]. The field data showed a long and slender depositional area in the point of the headlands on the offshore side, the numerical simulation using the FUNWAVE could reproduce the depositional area qualitatively.

Key Words : *Coastal erosion, Longshore sediment, Bathymetry, Fully nonlinear Boussinesq equation, Mayer-Peter and Müller formula*

1. INTRODUTION

Headland control is a preferable shoreline management technique. Many studies conducted on the sediment transport around headland: Sato et al.[2)] estimated effect of headland length on the longshore sediment trap and Uda et al.[3)] demonstrated an effective shape of headland. The longshore sediment transport at the Southern Sendai Coast was studied by Tanaka et al.[4)] and Tsukiyama et al.[5)]. They indicated that a headland can trap approximately 20% of longshore sediment. There are, however, few studies on sediment transport around headlands in the middle of their construction.

The purpose of this study is for better beach management, to understand characteristic of topographic change in the vicinity of headlands and effect of the headland on sediment transport, and to clarify its processes caused by interactions among wave, current and headland with numerical simulation.

2. STUDY AREA

The Southern Sendai Coast (Fig.1) is approximately 65-km long curved coast facing the Pacific Ocean in the northern part of Japan, where is

Table1 The average wave data using caluculation

	Summer wave	Winter wave
Height (m)	1.16	1.00
Period(s)	8.2	9.6
Angle(degree)	102.8	67.4

a typical coastal erosion area in Japan. Predominant wave direction is east to southeast, and the direction of longshore sediment transport is from south to north. The sediment was supplied to the coast by the erosion of coastal cliff located 50 km southern southeast of the coast before; however, because of prevention of the coastal cliff erosion and of development of extensive port between the coast and the cliff, the coast began to erode in 1970s. In order to prevent the erosion and control the longshore sediment transport, eight headlands with a length of 100m have been already constructed since 1997 at 1km intervals in Yamamoto Beach. The headlands will be extended to lengths of 200m, and additional headlands 500m intervals will be executed by 2056.

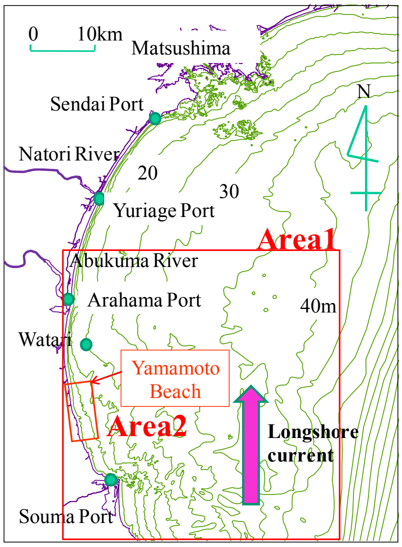

Fig.1 Bathymetric chart in the Southern Sendai Coast, Japan

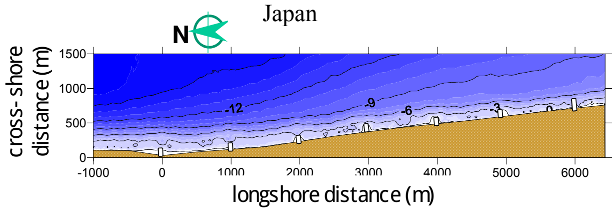

Fig.2 Bathymetric chart in theYamamoto Beach (Area2)

3. METHODOLOGY

(1) Field data analysis

Topographic data in the vicinity of headlands was obtained by the Ministry of Land, infrastructure and Transport in February 2002, February 2004, Nobember 2004, and February 2005. The data was obtained at intervals of approximately 20m in the cross-shore direction and 500m in the longshore direction over the area of Yamamoto Beach (2000m in the cross-shore and 8000m in the longshore). In the area around headland No.5 (HL5), more detailed data was obtained at intervals of approximately 10m in the cross-shore direction and 20m in the longshore direction over the area of HL5 (100m in the cross-shore and 200m in the longshore). In this study, both macroscale and medium scale topographic changes were investigated using data over the area of Yamamoto Beach and around HL5, respectively.

(2) Numerical analysis

a)Wave field analysis

The Watari observatory (water depth 20m) is the closest wave measurement point to the study area, but has many invalid data; therefore we used NOWPHAS (Nationwide Ocean Wave information network for Ports and HArbourS) data of the Soma observatory (water depth 17.1m) located at 10km southern from Yamamoto Beach, revised using data at Watari. The NOWPHAS data includes the significant wave height, period, and direction obtained every two hours. The wave direction is expressed clockwise from north, in positive degree from 0 degree. From this data, average wave conditions were calculated in the period of February 2004 to Nobember 2004 (summer condition), and Nobember 2004 to February 2005 (winter condition). The average significant wave height and period, direction are listed in **Table1**.

Macroscale wave field including Yamamoto Beach (**Fig.1**, Area1) has calculated using energy balance equation with the wave data, which was used as boundary contion: spatial distribution of water level and of bottom velocity has been calculated with FUNWAVE (Fully Nonliner Boussinesq Wave Model) in the Yamamoto Beach (**Fig.2**). The FUNWAVE is based on the fully nonlinear Boussinesq model of Wei et al[1]:

$$\frac{\partial \vec{u_\alpha}}{\partial t} + (u_\alpha\cdot\nabla)\vec{u_\alpha} + g\nabla\eta + z_\alpha\left[\frac{1}{2}z_\alpha\nabla\left(\nabla\cdot\frac{\partial\vec{u_\alpha}}{\partial t}\right)+\nabla\left\{\nabla\cdot\left(h\frac{\partial \vec{u_\alpha}}{\partial t}\right)\right\}\right]$$
$$+\nabla\left[\frac{1}{2}\left(z_\alpha^2-\eta^2\right)\left(\vec{u_\alpha}\cdot\nabla\right)\left(\nabla\cdot\vec{u_\alpha}\right)+\frac{1}{2}\left\{\nabla\cdot\left(h\vec{u_\alpha}\right)+\eta\nabla\cdot\vec{u_\alpha}\right\}^2\right]$$
$$+\nabla\left[\left(z_\alpha-\eta\right)\left(\vec{u_\alpha}\cdot\nabla\right)\left(\nabla\cdot\left(h\vec{u_\alpha}\right)\right)-\eta\left\{\frac{1}{2}\eta\nabla\cdot\frac{\partial\vec{u_\alpha}}{\partial t}+\nabla\cdot\left(h\frac{\partial\vec{u_\alpha}}{\partial t}\right)\right\}\right]$$
$$=0 \quad (1)$$

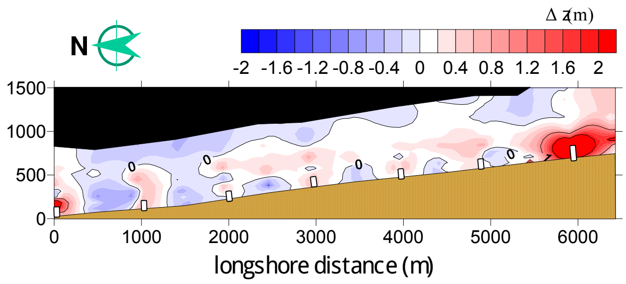

Fig.3 Topographic change at Yamamoto Beach from February 2002 to February 2005

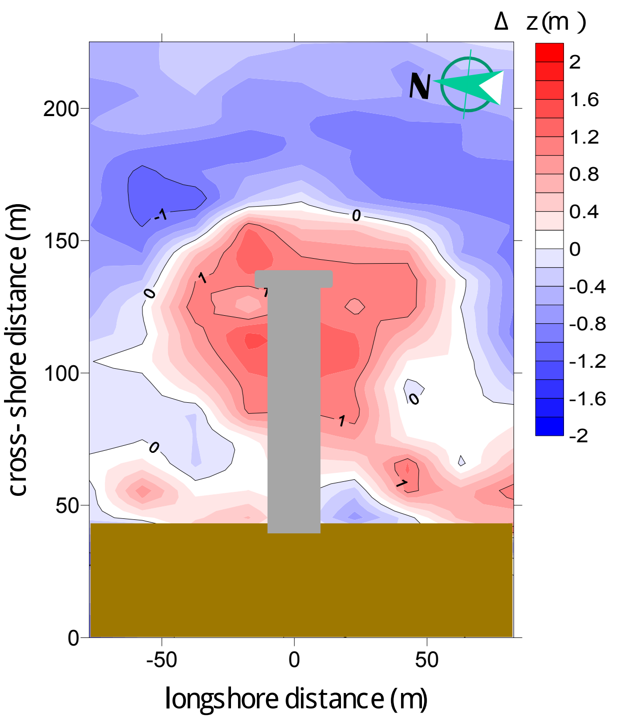

Fig.4 Topographic change in the vicinity of HL5 from Nobember 2003 to October 2005

$$\frac{\partial \eta}{\partial t} + \nabla[(h+\eta)A] = 0 \tag{2a}$$

$$\left\{\overrightarrow{u_\alpha} + \left(z_\alpha + \frac{1}{2}(h-\eta)\right)\nabla\left(\nabla\cdot\left(h\overrightarrow{u_\alpha}\right)\right) + \eta\left(\frac{1}{2}z_\alpha^2 - \frac{1}{6}(h^2 - h\eta + \eta^2)\right)\nabla\left(\nabla\cdot\overrightarrow{u_\alpha}\right)\right\} = A \tag{2b}$$

where η is the surface elevation, h is the still water depth, u_α is the horizontal velocity vector at $z_\alpha = -0.531h$. Initial topography was given by the observed data in 2003 of an area of **Fig.2**. Grid size was set at 10m.

b)Sediment transport filed analysis

The topographic changes in Yamamoto Beach during 2 hours for summer and winter wave conditions are calculated using the wave and current results obtained by FUNWAVE. As a calculation condition, median particle diameter and time step are given 0.26 mm and every 0.4 s, respectively.

The shear velocity and bottom shear stress are given as (3)and(4).

$$\frac{u_b}{u_*} = \frac{1}{\kappa}\ln\frac{z}{z_0} \tag{3}$$

$$\tau_b = \rho u_* |u_*| \tag{4}$$

where u_b is the bottom velocity, u_* is the shear velocity, z_0 is roughness height, z is height of velocity point grid, κ is the Karman constant, τ_b is the bottom shear stress. Boundary layer thickness δ is given by with displacement thickness δ^* by Kajiura[6] formula (5).

$$\delta = 4\delta^* \tag{5}$$

Near the breaking point, δ^* is about 1.0 cm. So it has caluculated that z as δ = 4.0 cm reference.

Sediment transport has been caluculated with Mayer-Peter and Müller[7] formular (6).

$$\Phi = 8(\theta_c - \theta_{cr})^{1.5} \tag{6}$$

where θ_c is Shields number , θ_{cr} is critical Shields number (=0.05).

4. RESULT AND DISCUSSION

(1) Characteristics of topographic change

The macroscale topographic change from February 2002 to February 2005 is shown in **Fig.3**. Similarly to existing studies, sedimentation occurred in the vicinity of the headland, though erosions occurred between the headlands. Furthermore, there is a long and slender depositional area appeared in the offshore side of seaward edges of headlands in the point of the headlands on the offshore side.

The macroscale topographic change in the vicinity of HL5 from November 2003 to October 2005 is shown in **Fig.4**. A depositional area appeared in the both side of the headland. It is considered to be caused by circulation current around the headland. Sato et al.[2] has pointed out possibility of reduction of erosion at the down-drift side of the deposition at the up-drift side on the basis of the calculation result of the current. In addition, it is thought that seaside

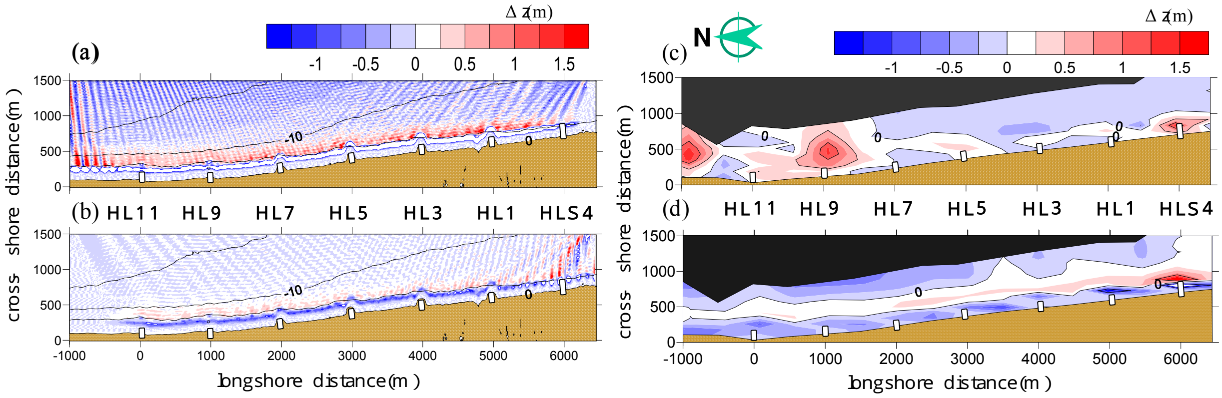

Fig.5 Topographic changes at Yamamoto Beach by numerical analyses for (a)summer and (b)winter wave conditions and field analyses and observation result (c)from February 2004 to Nobember 2004) (d)from Nobember 2004 to February 2005)

current acceleration occurred the erosion of the point of the head section.

(2) Comparison with simulation and observation result

Comparison of topographic changes at Yamamoto Beach obtained by numerical and field analyses for summer and winter condition are shown **Fig.5**. In order to compare, the topographic change value of numerical analyses adjusted same time scale with obseravation period.

Summer results have a simmiler characteristics which is long and slender depositional area in the point of the headlands on the offshore side (water depth is 5-10m). On the other hand, there is a erosion area near the shoreline. It seems that the sand near shore line is transported offshore due to the undertow. We could not reproduce a deposition area on the off shore side of HL9 which is come from the predominant wave direction from south to nouth, however; can reproduce erosinal trend throughout the area. Furthermore, several characteristics could be quantitatively reproduced such as depositional area in the point of the headlands on the offshore side (water depth is 5-10m) and erosinal area near the deposinal area on the onshore side.

5. Conclusions

From the topographical change in Yamamoto Beach, it has been understood that there is a long and slender depositional area in the point of the headlands on the offshore side.

The characteristics of erosion dependeds on the predominant wave angle of each season.

From the calculation, we could reproduce the characteristics in a shallow with a water depth of 5-10m deposited and the depth less than 5m eroded in summer, which is erosinal trend throughout the area in winter. Especially, some characteristics in winter could reproduced quantitatively.

ACKNOWLEDGMENT: This study was supported by Mr. Budianto Ontowirjo who was gratefully thanked for the calculations.

REFERENCES

1) Wei, G., J. T. Kirby, S. T. Grilli and R. Subramanya: A fully nonlinear Boussinesq model for surface waves. Part1. Highly nonlinear unsteady waves, J. Fluid Mech., vol. 294, pp.71-92, 1995.
2) Sato, S., Yamamoto, K., Wada, K., Izawa, T., Otani, Y. and Hashimoto, A.: Sediment observation and prediction of beach deformation around headland in Omagari Coast, Japan, Annual J.COASTAL ENGEERING, JSCE, Vol.45, pp. 556-560, 1998. (in Japanese)
3) Uda, T., Aoki, T., Hoshigaki Y., Furuike, K., and Nagayama, H.: Quantitative evaluation of obstruction effect of littoral drift by artificial headland, Proc. Civil. Engineering in the Ocean, vol. 23, pp.1237-1242, 2007. (in Japanese)
4) Tanaka, S., Sato, S., Koseki, K., Sasaki, K., Otani, Y. and Hashimoto, A.: Sediment transport around structure in the Southern Sendai Coastal, Annual J.COASTAL ENGEERING, JSCE, Vol.44, pp. 556-560, 1997. (in Japanese)
5) Tsukiyama,T., Kimura,A., Takagi,T. and Hashimoto,A. : About sediment supplemental ratio in the southern Sendai coast, Japan, Annual J.COASTAL ENGEERING, JSCE, Vol.50, pp. 521-525, 2003. (in Japanese)
6) Kajiura K (1968): A model of the Bottom Boundary Layer in Water Waves, Bulletin of the Earthquake Research Institute, Vol.46, pp.75-123.
7) Mayer-Peter, E., Müller, R., (1948) : Formulas for bed-load transport. Report on the 2nd Meeting International Association Hydraulic Structure Research. Stockholm, Sweden, pp39-64.